CHAPTER 1

INTRODUCTION

1.1 INVERTERS

DC drives were mostly preferred for a long time for adjustable speed applications because of its simplicity in control operations. AC motors, in particular, induction motors were just utilized in constant speed drives. With the recent advancements in semiconductor technology and also due to the reduction in cost of power electronic components, it has become possible to build variable speed induction motor drives (or) adjustable AC drives. These AC drives can match and in some cases even surpass DC drives in performance and cost. Hence adjustable speed AC drives is an area of great interest in recent times and also finding more share in marketplace. In particular, military, aerospace and automotive industries are increasingly adopting variable AC speed drives in order to improve overall system efficiency and performance. There are certain safety critical applications such as steering, fuel pumps, and brake-by-wire systems, where operation of the drive is of paramount importance and continuous operation of the system must be insured. As a result, adjustable AC drives are often employed for these systems.

An efficient method of speed control of AC drives can be obtained by adjusting the stator voltage and frequency supply to induction motor. The major equipment necessary for this application is an inverter. The DC-AC converter, also known as the inverter, converts DC power to AC power at desired output voltage and frequency.

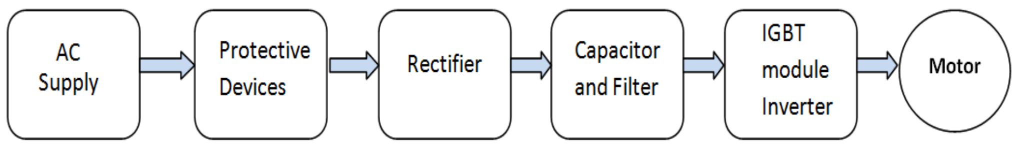

Figure 1.1 Block diagram of adjustable AC drive system connected with an inverter

Figure 1.1 shows the schematic of adjustable AC drive connected with an inverter. In general, the DC power input to the inverter is obtained from an existing power supply network or from a rotating alternator through a rectifier or a battery, fuel cell, photovoltaic array or magneto hydrodynamic generator. The filter capacitor across the input terminals of the inverter provides a constant DC link voltage. The inverter therefore is an adjustable-frequency voltage source, i.e. inverter is used to control the fundamental voltage magnitude and the frequency of the AC output voltage. AC loads may require constant or adjustable voltage at their input terminals, when such loads are fed by inverters, it is essential that the output voltage of the inverters is so controlled as to fulfill the requirement of the loads. For example if the inverter supplies power to a magnetic circuit, such as a induction motor, the voltage to frequency ratio at the inverter output terminals must be kept constant. This avoids saturation in the magnetic circuit of the device fed by the inverter. The configuration of AC to DC converter and DC to AC inverter is called a DC-link converter.

In general there are two types of inverters:

- Voltage Source Inverters (VSI)
- Current Source Inverters (CSI)

A Voltage–Fed Inverter (VFI) or more generally a Voltage–Source Inverter (VSI) is one in which the DC source has small or negligible impedance. The voltage at the input terminals is constant. A Current–Source Inverter (CSI) is fed with adjustable current from the DC source of high impedance that is from a constant DC source. If the voltage source inverter is employing thyristors as switches then forced commutation is required. If the VSIs are made up of using GTOs, power transistors, power MOSFETs or IGBTs, then self-commutation with base or gate drive signals for their controlled turn-on and turn-off is used. In the smaller/medium horse power range of industrial applications, the voltage source inverter type is the most popular one.

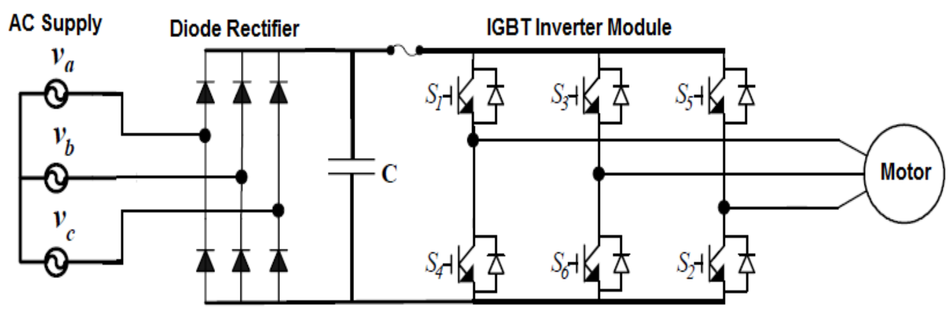

Figure 1.2 Schematic of 3φ IGBT inverter module connected with motor

Figure 1.2 shows a general schematic of a 3 phase (3ϕ) IGBT inverter module connected with a motor. It consists of a three phase power supply, rectifier module, filter capacitor and IGBT inverter module. A standard single-phase voltage or current source inverter can be in the half-bridge or full-bridge configuration. The single-phase units can be joined to have three-phase or multiphase topologies. Three phase inverters are used in many industrial applications of adjustable speed drives, such as induction heating, standby aircraft power supplies, UPS (uninterruptable power supply) for computers, High-Voltage Direct-Current (HVDC) transmission lines, etc.

1.2 MULTILEVEL INVERTER

In recent years, electric power industry has begun to demand higher power ratings. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. An adjustable speed inverter drive in megawatt level is normally interfaced with a medium voltage network. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel inverter structure has been introduced as an alternative in high power and medium voltage situations, and also Multi Level Inverter Drive (MLID) systems have become a solution for high power drive applications.

Multilevel inverters are finding increased attention in industry and academia as one of the preferred choices of electronic power conversion for high-power applications (Abul Masrur et al 2010). They have successfully made their way into the industry and therefore can be considered a mature and proven technology. Presently, they are commercialized in standard and customized products that power a wide range of applications, such as compressors, extruders, pumps, fans, grinding mills, rolling mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, mine hoists, reactive power compensation, marine propulsion, High-Voltage Direct-Current (HVDC) transmission, hydro pumped storage, wind energy conversion, and railway traction, to name a few (Abul Masrur et al 2010).

Inverters for these applications are commercially offered by a growing group of companies in the field (Estima & Marques Cardoso 2013). Although it is an enabling and already proven technology, multilevel inverters present a great deal of challenges, and even more importantly, they offer such a wide range of possibilities that their research and development is still growing in depth and width. Researchers all over the world are contributing to further improve energy efficiency, fault diagnosis, reliability, power density, simplicity, and cost of multilevel inverters, and broaden their application field as they become more attractive and competitive than classic topologies. Recently, many publications have addressed multilevel inverter technology and stressed the growing importance of multilevel inverters for high-power applications (Banaei & Salary 2011).

The concept of multilevel inverters has been introduced since 1975 (Alian Chen et al 2005). Despite that plentiful multilevel inverter topologies have been developed during the last two decades, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage DC sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple DC voltage sources. The commutation of the power switches aggregate these multiple DC sources in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the rating of the DC voltage sources to which they are connected.

1.3 TYPES OF MULTILEVEL INVERTER

The traditional and well-established multilevel inverter topologies are,

- Cascaded H-Bridge (CHB) Inverter
- Neutral Point Clamped (NPC) Inverter
- Flying Capacitor (FC) Inverter.

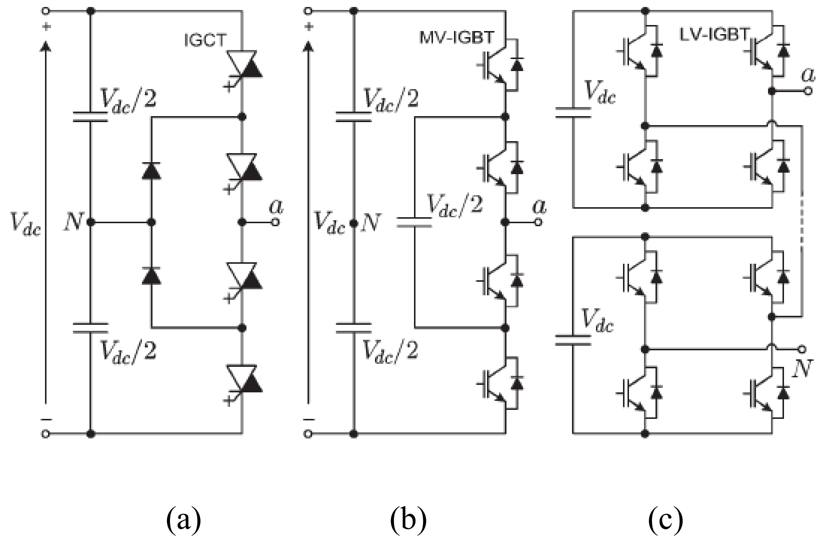

Figure 1.3 Classic multilevel converter topologies (a) 3L-NPC featuring IGCTs (b) Three-level FC featuring MV-IGBTs (c) Five-level CHB featuring LV-IGBTs

Multilevel inverter technology started with the introduction of the multilevel stepped waveform concept with a series-connected H-bridge, which is also known as cascaded H-Bridge converter, in the late 1960s (Jianghan Zhang et al 2014). This was closely followed by low-power development of an FC topology the same year (John Chiasson et al 2003). Finally, in the late 1970s, the Diode-Clamped Converter (DCC) was first introduced (Jorge & Antonio 2013). The three-level NPC (3L-NPC) inverter was proposed (Kavitha & Sujitha 2014) and can be considered as the first real multilevel power converter for medium-voltage applications.

Figure 1.3 shows the circuit diagrams of a single-phase leg of three multilevel inverter topologies with commonly used semiconductor devices. These three multilevel converter topologies are considered as the traditional multilevel topologies that first made it into real industrial products during the last two decades. These converters are commercialized by several manufacturers in the field (Jiangbiao & Nabeel 2014), offering different power ratings, front-end configurations, cooling systems, semiconductor devices, and control schemes, among other technical specifications. The NPC features medium-/high-voltage devices [integrated Gate-Commutated Thyristor (IGCT) and medium voltage/ high-voltage Insulated-Gate Bipolar Transistors (IGBTs)], whereas the CHB exclusively uses low-voltage IGBTs (LV-IGBTs). The 3L-NPC and the CHB are the most popular multilevel topologies used in the industry.

In recent times, cascaded multilevel inverters are mostly preferred for large electric drives used in industries and hybrid electric vehicles because of its advantages such as low harmonics, flexibility to use a set of batteries or fuel cells or any renewable energy sources in any intermediate stage of inverter and ability to reach desired high voltages (Alian Chen et al 2005). Figure 1.4 shows the schematic of single phase structure of a m-level cascaded H-bridge multilevel inverter. Each Separate DC Source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, +Vdc, 0, and –Vdc by connecting the DC source to the AC output by different combinations of the four switches, S1, S2, S3, and S4. To obtain +Vdc, switches S1 and S4 are turned on, whereas –Vdc can be obtained by turning on switches S2 and S3. By turning on S1 and S2 or S3 and S4, the output voltage is 0. The AC outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by $m = 2s+1$, where's' is the number of separate DC sources.

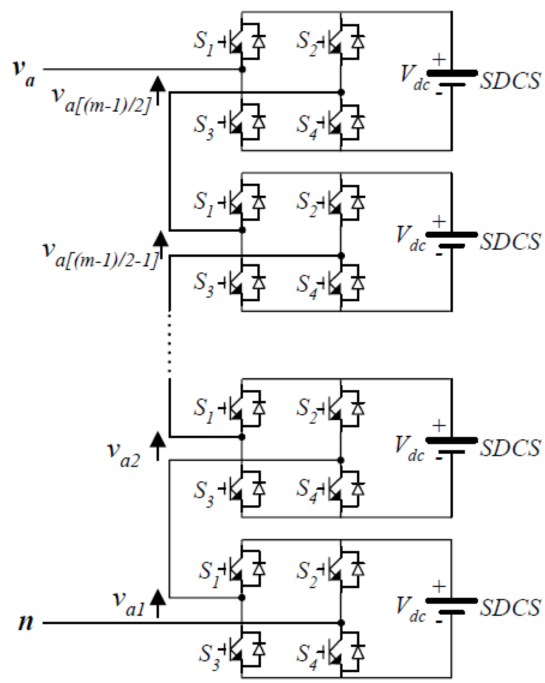

Figure 1.4 Schematic diagram of single phase cascaded H-bridge multilevel inverter

A cascade MLID is a general fit for large automotive all-electric drives because of the high VA rating possible and because it uses several DC voltage sources which would be available from batteries or fuel cells. A CHB multilevel inverter not only achieves high power ratings, but also enables the use of renewable energy sources such as photovoltaic, wind, and fuel cells that can be easily interfaced to a multilevel converter system for a high power application. Cascaded inverters have also been proposed for use as the main traction drive in electric vehicles, where several batteries or ultra capacitors are well suited to serve as Separate DC Sources (SDCS)s (Abul Masrur et al 2010). The cascaded inverter could also serve as a rectifier/charger for the batteries of an electric vehicle while the vehicle was connected to an AC supply. Additionally, the cascade inverter can act as a rectifier in a vehicle that uses regenerative braking. The main advantages of multilevel cascaded H-bridge inverters are that the number of possible output voltage levels is more than twice the number of DC sources ($m = 2s + 1$), where ‘m’ is the number of possible outcome voltage level and ‘S’ is the number of H-Bridge units used in the system and the series of H-bridges makes for modularized layout and packaging which will enable the manufacturing process to be done more quickly and cheaply.

A number of papers have recently been published comparing the three topologies, such as NPC, CHB and FC, for specific applications in terms of the losses and the output voltage quality (Pablo Barriuso et al 2009). The CHB is well suited for high-power applications because of the modular structure that enables higher voltage operation with classic low-voltage semiconductors. The phase shifting of the carrier signals moves the frequency harmonics to the higher frequency side, and this, together with the high number of levels, enables the reduction in the average device switching frequency ($\leq$ 500 Hz), allowing air cooling and lower losses. However, it requires a large number of isolated DC sources, which have to be fed from phase-shifting isolation transformers, which are more expensive and bulky, compared with the standard transformer used for the NPC. Nevertheless, this has effectively been used to improve the input power factor of this converter, reducing input current harmonics.

1.4 ADVANTAGES OF MULTILEVEL INVERTERS

A multilevel inverter has several advantages over a conventional two-level inverter that uses high switching frequency pulse width modulation (PWM). The attractive features of a multilevel inverters can be briefly summarized as follows:

- Multilevel inverters can generate near sinusoidal voltages with only fundamental frequency switching.

- Multilevel inverters not only can generate the output voltages with very low distortion, but also can reduce the *dv/dt* stresses; therefore Electromagnetic Compatibility (EMC) problems can be reduced.
- Multilevel inverters produce smaller common mode voltage, therefore, the stress in the bearings of a motor connected to a multilevel motor drive can be reduced. Furthermore, common mode voltage stress can be eliminated by using advanced modulation strategies.
- Multilevel inverters can draw input current with low distortion.
- Multilevel inverters can operate at both fundamental switching frequency and high switching frequency PWM. It should be noted that lower switching frequency usually means lower switching loss and higher efficiency.
- Multilevel inverters are suitable for large volt ampere-rated motor drives and high voltages.

1.5 IMPORTANCE OF FAULT DIAGNOSIS OF MULTILEVEL INVERTERS

Even though multilevel inverters have many advantages and mostly preferred in recent times for industrial applications, they still suffer from the occurrence of various faults. The most common faults occurring in the case of multilevel inverter drive system are open-circuits or short-circuits in inverter power electronic switches, motor single-phasing, or DC link capacitor short-circuit. In general, inverter power electronic component failures can be broadly classified as open-circuit faults and short-circuit faults. Any fault in a semiconductor power switch is that fails to operate when provided gate drive signals which may be due to short circuit or open circuit. Open-circuit faults of power electronic switches do not necessarily cause the system shutdown and can remain undetected for an extended period of time. This may lead to secondary faults in the inverter or in the remaining drive components, resulting in the total system shutdown and high repairing costs. On the other hand, short-circuit faults of power electronic switches are very destructive and requires special measures to shut down the entire drive immediately.

Since multilevel inverters are used in high power and expensive applications, considering the investment cost and safety aspects, it is necessary to maintain the reliability of the system. In the case of multilevel inverters, reliability is mainly affected by the electronic components, mainly because of increase in number of power electronic switches (such as IGBT and MOSFET) which are considered as the weakest part of the system. Once a fault in the switch occurs, it should be detected at the earliest in order to avoid the operation of drive and motor under abnormal conditions, which may lead to the failure of motor or drive and major economic losses.

In general, inverter-side faults generate load disturbances related to the presence of a pulsating electromagnetic torque and a substantial DC component in the stator currents. This component produces a rise in stator winding temperature, due to excessive losses. Rectifier-side faults lead to non-balanced injected currents in the mains supply, which create disturbances in mains voltage. One particular effect on a faulty switch is unbalance output voltage of a MLID. In a balanced MLID system, the three line to neutral output voltages are equal in magnitude and are phase displaced from each other by 120 degree. On the other hand, if a fault occurs at a semiconductor power switch in a cell, it will cause an unbalanced output voltage, which also causes the line to line output voltages to also be unbalanced. Voltage unbalance also has an impact on a conventional inverter drive system where the front end consists of three-phase rectifier systems. The triplen harmonic line currents which are uncharacteristic to these rectifier systems can exist in these situations leading to unexpected harmonic problems (Behrooz 2014).

An excessive level of unbalanced output voltage can have serious impacts on mains connected to an induction motor. The level of an unbalanced current may have several times the level of an unbalanced voltage. The unbalanced current in a line current can lead to disproportionate losses in the rotor and stator of the induction motor. Some induction motors are designed to tolerate a small level of unbalanced voltages and currents; however, they have to be derated if the unbalance is excessive. An induction motor that operates at its nameplate rated capacity without derating even though required load is not at rated capacity because of the unbalance voltages from a MLID will result in the useful lifetime of such an induction motor to be quite short. If the induction motor operates at full load all the time, the stator windings and the rotor may carry more current than that is permitted: this situation can lead to a reduction in induction motor efficiency and can reduce the insulation life caused by overheating.

The average expected life of insulation halves for every 10°C of temperature increase as reported in (Behrooz 2014). Moreover, an induction motor operating under unbalanced voltage condition will be noisy in its operation caused by torque and speed pulsation. Obviously, in such situations the effective torque and speed will be less than normal. Multilevel inverters provide more possibilities in the power circuit to operate under faulty conditions; however, faults should be detected as soon as possible after they occur, because if a motor drive runs continuously under abnormal conditions, the drive or motor may quickly fail. Thus, knowledge of fault behaviors, fault prediction, and fault diagnosis are necessary.

1.6 CONVENTIONAL FAULT DIAGNOSIS AND PROTECTION SYSTEM

Heavy industrial applications such as industrial manufacturing process are dependent upon induction motors and their inverter drive systems for process control. The reliability of power electronics components is of paramount importance in industrial, commercial, aerospace, and military applications. The knowledge about the fault mode behavior of an inverter system is extremely important from the standpoint of improved system design, protection, and fault tolerant control. Generally, the conventional fault protection systems are passive devices such as fuses, overload relays and circuit breakers to protect the inverter systems and the induction motors. The protection devices will disconnect the power sources from the multilevel inverter system whenever a fault occurs, stopping the operated process. Downtime of manufacturing equipment can add up to be thousands or hundreds of thousands of dollars per hour; therefore, fault detection and diagnosis is vital to a company's bottom line.

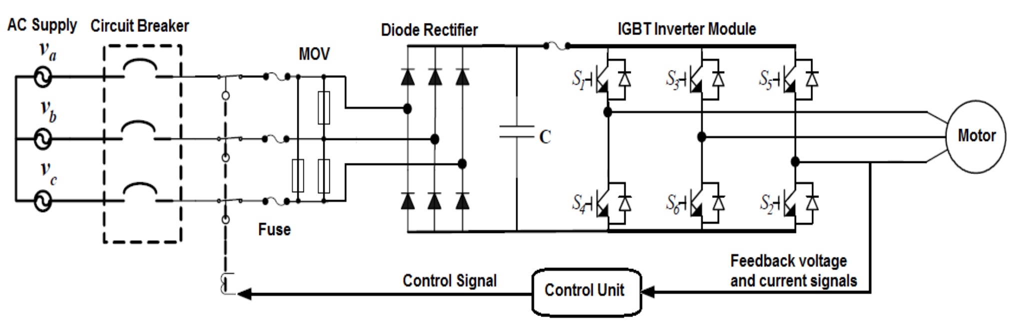

Figure 1.5 Conventional fault diagnosis and protection system of voltage source inverter drive

Figure 1.5 shows the conventional fault diagnosis and protective system of a voltage source inverter drive used in industries. The inverter drive consists of six diodes on the input side, DC link voltage, and six semiconductor power switches on the output side. The conventional protection system is mostly passive devices such as fuses, circuit breakers (CBs), and overload relays as illustrated in Figure. This protection system can protect against ground faults, DC link overvoltage and under voltage, and inverter over current. For instance, the input circuit breaker will trip for steady over current to the inverter, and the input fuses will blow for short circuit fault of a diode in rectifier or a DC link capacitor. The inverter input fuse at DC link will protect the rectifier and filter capacitor from a shoot-through fault in the inverter. The metal oxide varistors at the input side will protect against overvoltage. The over temperature of a motor will be protected by circuit breaker activated by thermal relay.

The protection system is normally designed to shut down the inverter drive to protect the power circuit, overlooking the consequence of such accidental shut down. For instance, in the case of an inverter fault such as open or short circuit in a power switch, the fuse in DC link will blow when the current reaches to the safety limit, disconnecting the DC voltage supply. This may cause vitally consequent damages in the motor if the motor is running at base speed with rated load. Therefore, the passive protection system may not be adequate if the application of inverter drive needs a continuous operation or the motor is connected with a large load such as conveyer or hybrid/electric vehicle. It would be better if one can isolate the fault and continue to operate the motor with a single phase mode with degraded motor performance.

The new generation of power semiconductor switches for a conventional inverter drive is mostly designed as modular package known as intelligent power module. An intelligent power module usually combines a single phase or three phase rectifier and three phase inverter, gate drive circuit and protection circuit as one package. However, the intelligent power module of conventional inverter drive will normally turn off all gate drive signals as soon as a fault is detected; as a result, the inverter drive will stop operation.

1.7 DRAWBACKS OF CONVENTIONAL FAULT DIAGNOSIS TECHNIQUES

The use of the Park's vector approach as a fault diagnostic tool for voltage source inverter faults was applied in (Brian 2004). Park's vector approach has some drawbacks such as,

- This approach requires very complex pattern recognition algorithms.
- This approach is not suitable for integration into the drive controller.

Primarily, the fault detection and diagnosis techniques can be classified as model based technique and model-less based technique. A model-based technique principally depends upon a mathematical model; for instance, analytical redundancy method and parameter estimation method. Model based technique has many disadvantages such as,

- A model based technique is valuable only if an accurate model of faults can be obtained.
- In the case of a multilevel inverter drive, an accurate model representing all of the possible fault cases is difficult to obtain.
- Expensive in engineering time to develop model
- Model may not be robust to nonlinear problems

- Model may not be robust to seasonal changes or plant degradation.

A model-less based technique is based upon expert-knowledge or artificial intelligent system. An implementation of a model-less technique may be more expensive than a model based technique; however, the technology promise of very large scale integration (VLSI) technology would reduce the implemented cost.

1.8 PROBLEM FORMULATION

In the case of multilevel inverters, reliability is mainly affected by the electronic components, mainly because of increase in number of power electronic switches such as IGBT and MOSFET which are considered as the weakest part of the system. Once a fault in the switch occurs, it should be detected at the earliest in order to avoid the operation of drive and motor under abnormal conditions, which may lead to the failure of motor or drive and major economic losses. Fault diagnosis of multilevel inverters is a hot research topic and has created lot of interest among many researchers in the development of better fault diagnostic techniques and protection system. Open circuit and short circuit faults are the most common failures in semiconductor switches and leads to failure of battery or load connected to the inverter (Banaei 2012).

Several techniques have been proposed to identify the faulty switches of inverters based on current measurement and analysis. Since the output current of inverter is dependent on nature of load, accurate fault detection is difficult under low current values. Many researchers developed the fault diagnostic system from the inverter output voltage measurement, because it is independent of load variations (Estima & Marques Cardoso 2013). Surin Khomfoi et al, developed a open-switch fault diagnostic system of a multilevel inverter from the features of output voltage waveform extracted from the FFT analysis and given as an input to neural network which resulted in 40 input neurons and five parallel neural networks. Size of the neural network and number of input neurons is higher in this approach. In order to reduce the size of the neural network,

Surin Khomfoi et al, proposed combination of FFT, principal component analysis, genetic algorithm and neural network in the processing of output voltage waveform to detect the fault type and fault location. In general, FFT is inadequate to track the changes in the non-stationary voltage signal magnitude, frequency or phase. Identification of switch fault of multilevel inverters is still a hot research topic and many researchers are working hard to identify the fault accurately. However, reports on implementation of high performance fault diagnostic system for cascaded H-bridge multilevel inverter are scanty.

It is necessary to adopt Artificial Intelligence (AI) based techniques such as Neural Networks (NN), Fuzzy Logic (FL), etc. for the development of high performance fault diagnostic system for multilevel inverters. The advantages of Artificial Intelligence based techniques are,

- They are mostly non-linear;
- They have input-output mapping and adaptivity: the model can be trained to perform a desired mapping;
- They have fault tolerance capability: the failure of single neuron will only partially degrade performance
- It can be implemented with advanced data acquisition system and software techniques.

The AI-based controllers could lead to improved performance, enhanced tuning and adaptive capabilities. It is possible that AI-based technique can be applied in condition monitoring and diagnosis. By using condition monitoring, vast savings may be made through improved maintenance procedures and policies. AI-based condition monitoring and diagnosis have several advantages; for instance, AI-based techniques do not require any mathematical models, therefore the engineering time and development time could be significantly reduced. AI-based techniques utilize the data sets of the system or expert knowledge. Moreover, the reliability of the system can also improve by using diagnosis; for example, in MLID applications, several types of signals such as voltage, current, noise, vibration, temperature, and flux signals which can convey valuable information for diagnosis on the electrical and mechanical state of a MLID system including motor, multilevel inverter and controller. The voltage and/or current signals could be used to diagnose a drift of power semiconductor switches in the multilevel inverter which contains numerous semiconductor switches.

Considering these facts, in the present work, inverter output voltage is considered for open circuit and short circuit fault identification purpose, because it is independent of load variations. Discrete Wavelet Transform (DWT) is most suited for non-stationary signals and it provides good time-frequency resolution. Multi Resolution Analysis (MRA) of DWT has been used in several power system research works successfully (Fiorenzo Filippettiet al 2000). Chandrasekar et al applied the DWT MRA technique to classify the surface pollution severity of power transmission line system. Hence, in this work energy content of the signal at different level of decomposition of DWT MRA is considered as an important feature of the signal and hence it can be used to identify the faulty switches.

AI-based techniques are mainly applied to fault diagnostic task. Fault identification is a part of a protection paradigm and can also be considered as pattern recognition problems or non-linear problems. Therefore, Artificial Neuron Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) technique can be used to perform the fault classification. These techniques permit input/output mapping with a nonlinear relationship between nodes; also, these techniques provide the ability to recognize anomalous situations because of their intrinsic capacity to classify and generalize.

Especially, the sensitivity and response time of the original procedure presented for the on-line analysis of fault set repetition enable on-line fault location techniques to be developed (chandrasekar et al 2009). The normal and abnormal data or signals can be used to train the networks, so that the neural network can have ability to classify the difference between normal and abnormal condition of the system. ANFIS is a powerful tool in the classification of patterns through learning and nonlinear mapping. ANFIS is composed of fuzzy inference systems implemented in the framework of adaptive networks. Hence, in this research work, fault identification process is automated through ANN approach and ANFIS technique. Application of DWT features in the ANN or ANFIS network reduces number of inputs and size of the network and hence avoids the usage of any intermediate statistical or computational processes to reduce the size of the network and in turn reduces the computational time.

1.9 RESEARCH OBJECTIVES

The key objective of the present research work is to develop a high performance fault diagnostic system for identifying open circuit and short circuit faults of cascaded H-bridge multilevel inverter using advanced signal processing techniques and soft computing techniques. The major objectives of this research work are,

1. To analyze both open circuit and short circuit faults of power electronic switches in the cascaded H-bridge multilevel inverters connected with induction motor drive
2. To understand the output voltage waveform pattern of multilevel inverter at different switch fault cases.
3. To study the time domain characteristics of output voltage waveforms at different fault cases using voltage ratio analysis
4. To analyze the frequency domain characteristics of output voltage waveforms at different fault cases using FFT analysis
5. To analyze the time-frequency domain characteristics of output voltage waveforms at different fault cases using advanced discrete wavelet transform technique
6. To extract salient features of the output voltage signal such as energy content and harmonic ratios of the output voltage signal at different fault cases from the FFT analysis and DWT MRA analysis.
7. To compare the simulated and experimental results and validate the proposed approach of fault diagnosis of multilevel inverters
8. To develop artificial neural network based automated fault diagnostic system for identification of individual faulty switch.

9. To evaluate the performance of adaptive Neuro fuzzy inference system for identifying faulty switch of multilevel inverter.

10. To compare the performance characteristics of both ANN and ANFIS approach using the features extracted from both FFT and DWT MRA techniques.

1.10 ORGANIZATION OF THE THESIS

Chapter1 provides a general introduction about the topic of multilevel inverter and various faults on it. It also discusses about the concepts of conventional fault diagnostic techniques and its drawbacks. Key objectives of the works are also discussed in this chapter.

Chapter 2 discusses about the various research papers already published in the literatures on the various fault diagnostic techniques of multilevel inverters. Applications of various signal processing techniques and soft computing techniques already published in the literatures are also discussed.

Basic concept of signal processing techniques such as Fast Fourier Transform (FFT) and Multi resolution signal decomposition using Discrete Wavelet Transform (DWT) are discussed in chapter 3.

Overview of soft computing techniques such as Artificial Neural Networks (ANN) and Adaptive Neuro- Fuzzy Inference System (ANFIS) and concept of classification of signals using these techniques are discussed in chapter 4.

Chapter 5 explains in detail about the experimental setup used in the present work for fault analysis and the simulation technique used for the study of cascaded H-bridge multilevel inverter at different fault cases. Chapter 6 discusses the experimental and simulation results of output voltage and current waveforms of five level cascaded multilevel inverter at different fault cases.

Feature extraction from the output voltage waveform at different fault cases using FFT and DWT signal processing techniques is explained in chapter 7. Fault diagnosis results of multilevel inverter using the soft computing techniques such as ANN and ANFIS are discussed in chapter 8. Chapter 9 discusses in detail the various conclusions obtained in the present research work.